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(54) Title: METHOD, SYSTEM, AND APPARTUS OF CUTTING EARTHEN FORMATIONS AND THE LIKE

(57) **Abstract:** A cutter element is provided for use on a rotary drill bit of a drilling string to cut earthen formation and the like. The cutter element includes a cutting portion formed from cutting material adapted to cut into the earthen formation, and a substrate positioned adjacent the cutting portion. The cutting portion and the substrate form a body having a substantially planar front face, a longitudinal axis extending centrally through the front face and the substrate, and a circumferential surface extending inwardly form the front face and spaced outwardly from the longitudinal axis. The cutting portion includes a cutting face that provides at least a portion of the front face. The cutting portion extends longitudinally inward from the front face to a back surface engaging or interfacing the substrate. Thus, a distinct, longitudinally extending volume of cutting material is provided and includes a predesignated portion of the circumferential surface that extends from the cutting face to the back surface, the circumferential surface portion being predesignated for wearing contact with the earthen formation.

Docket No: PDI-1000WO00

METHOD, SYSTEM, AND APPARATUS OF CUTTING EARTHEN FORMATIONS AND THE LIKE

[0001] The present application claims the benefit of the filing date of United States Provisional Application Serial No. 60/473,832, filed May 27, 2003 (pending) (hereby incorporated by reference for all purposes and made a part of the present disclosure).

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

[0002] The present invention relates to methods, systems, and/or apparatus for cutting earthen formations that may be above ground or subterranean, and, more particularly, but not by way of limitation, to methods of and apparatus for cutting earthen formations for various applications such as oil, gas, and geothermal production, in addition to excavations including tunnels, pipe chases, foundation piers, building stone, quarried rock, etc.

DESCRIPTION OF THE RELATED ART

[0003] The prior art is replete with designs for cutting elements or cutters secured on a drill bit and utilized in the drilling of well bores or the cutting of formations for the construction of tunnels and other subterranean earthen excavations. One type of conventional cutter is a polycrystalline diamond cutter (PDCs) that is axisymmetric and includes a diamond table attached to a substrate, usually tungsten carbide. Such a cutter is described in U.S. Patent Nos. 4,552,232, 4,981,183, and

5,119,511, which are hereby incorporated by reference for all purposes and made a part of the present disclosure.

[0004] The life of the cutter is controlled largely by wear or fracture. Fracture is typically a result of a combination of applied cutting loads and stresses associated with the cutter geometry and stresses residual to the high pressure/high temperature manufacturing process. Wear is a function of diamond feed stock size, integrated metallurgy, and "sintering" conditions. Wear is also a function of the volume of the diamond available at the cutting interface between the cutter and the rock formation.

[0005] FIG. 1 illustrates a prior art cutting element or cutter 110 engaging an earthen formation 112. The cutter 110 has a front or cutting face 120 and circumferential all-around wall or surface 118 extending longitudinally inwardly therefrom. The conventional cutter 110 includes a cutting surface or table 122 and a substrate 124 positioned adjacent thereto. The cutting table 122 has a front planar surface that provides the cutting face 120 and a back face 110a positioned adjacent a forward planar face of the substrate 124. The back face 110a is planar, in parallel relation with the cutting face 120, and thus, generally normal to the longitudinal axis, L.

[0006] As shown in FIG. 1, the cutter 110 may be inclined with a negative back rake angle, θ, to the direction of travel 114 in the rock formation 112. In order to keep the cutter 110 buried at a constant depth 116 in the cut, a normal load, N, is applied to the cutter 110 (often referred to as the weight on bit (WOB)). A load, L, is also applied in the direction of the cut, forcing the cutter 110 to abrade the rock formation 112 and displace rock fragments 112a. This load, L, is a result of the torque applied to a rotating bit and transferred to the cutter 110 secured therein.

[0007] In general, only a portion of the cutter 110 actually contacts the rock formation 112. This includes a portion 126 of the cutting face 120 and a portion of the circumferential surface 118. As this contact area increases to cause diamond abrasion (*i.e.*, wearing contact), it is referred to as the wear flat. FIGS. 2A-2D illustrate the process of wearing as applied to a conventional cutter 210 contracting a rock formation. FIG. 2A illustrates a substantially uniform and unworn cutter 210. FIG. 2A illustrates the formation of a wear flat 228 on the cutter 210 after operation in the formation. The wear flat 228 is, however, confined to the cutting surface or diamond surface 222 of the cutter 210. After continued use, the wear flat 228 is worn further, as shown in FIG. 2C. At this point, the wear flat 228 extends from the cutting table 222 and into the substrate 224, thereby exposing the material of the substrate 224. In the side view of FIG. 2D, the wear flat 228 is shown extending well into the substrate. Such exposed substrates have high rates of failure and therefore may lead to the progressive failure of the entire drill bit. Bit failures cost time and money through reduced performance and additional trip time.

SUMMARY OF THE INVENTION

[0008] In one aspect of the present invention, a cutter element is provided for use on a rotary drill bit of a drilling string to cut earthen formations and the like. The cutter element includes a cutting portion formed from cutting material (*e.g.*, polycrystalline diamond) adapted to cut into the earthen formation, and a substrate positioned adjacent the cutting portion. The cutting portion and the substrate form a body (*e.g.*, substantially rod shaped) having a substantially planar front face, a longitudinal axis extending centrally through the front face and the substrate, and a circumferential surface extending inwardly from the front face and spaced outwardly

from the longitudinal axis. The cutting portion includes a cutting face that provides at least a portion of the front face. The cutting portion extends longitudinally inward from the front face to a back surface engaging or interfacing the substrate. Thus, a distinct, longitudinally extending volume of cutting material is provided and includes a predesignated portion of the circumferential surface that extends from the cutting face to the back surface, the circumferential surface portion being predesignated for wearing contact with the earthen formation.

[0009] In a method according to he invention, operation of a drill bit having such a cutting elements generates a wear flat along the predesignated portion of the circumferential surface.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a more complete understanding of the present invention, and for further objects and advantages thereof, reference is made to the following description taken in conjunction with the accompanying drawings in which

[0011] FIG. 1 (Prior Art) is a side view of a prior art cutter engaging a rock formation;

[0012] FIG. 2 (Prior Art) is an illustration of the progressive wear of the prior art cutter of FIG. 1;

[0013] FIGS. 3A-3C are illustrations of one embodiment according to the present invention;

[0014] FIG. 3D is an illustration of the cutter of FIG. 3A-3C engaging a rock formation;

[0015] FIG. 4 is an illustration of an alternate embodiment of the cutter of the present invention;

[0016] FIG. 5 is an illustration of an alternate embodiment of the cutter of the present invention;

[0017] FIG. 6 is an illustration of alternate embodiment of the cutter of the present invention;

[0018] FIG. 7 is an illustration of an alternate embodiment of the cutter of the present invention;

[0019] FIG. 8 is an illustration of an alternate embodiment of the cutter of the present invention;

[0020] FIG. 9 is an illustration of a worn cutter of one of the embodiments of the present invention; and

[0021] FIG. 10 is an illustration of a worn cutter of one of the embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0022] FIGS. 3A, 3B, and 3C provide front, longitudinal (vertical) cross-sectional, and bottom views, respectively of a cutting element or cutter 310 according to the present invention. The longitudinal axis ZZ may be described as dividing the cross-section into two halves.

[0023] The cutter 310 has a front or cutting face 320 outlined by a circumference or peripheral edge 320a (which may be a chamfered, beveled, or straight edge), and the longitudinal axis, ZZ, extending from the center of the cutting face 320 and generally normal thereto. The cutter 310 includes a substantially forward cutting portion 322 that is preferably comprised of polycrystalline diamond material and thus, referred to as a diamond table. In other embodiments, the material for the cutting portion may be tungsten carbide, cubic boron nitride, or other

commonly used materials. The cutter 310 further includes a substantially rearward portion provided by a substrate 324. The substrate 324 is preferably formed from tungsten carbide material, and, in other applications, other carbide materials having suitable thermal expansion properties relative to the that of the cutting material.

[0024] Referring to the cross-sectional view of FIG. 3B, the lower half of the cutter 310 includes substantially more area of the cutting portion 322 than the upper half. As shown therein, the back surface 320A of the cutting portion 322 that interfaces the substrate 324 is non-planar, in contrast to the substantially planar surface of the cutting face 320. The inward back surface 320A is also oriented at an angle other than normal in respect to the longitudinal axis, ZZ. Accordingly, the cutting material 322 extends longitudinally inward more so at different radii locations (and in certain sectors) than in others. In other word, the longitudinal distance, *e.g.*, distances 320B, 320C, between the front face 320 and the back face 320A vary. For example, an exposed surface 350 shown in FIG. 3B extends from the cutting face 320 longitudinally inward through a distance or depth significantly greater than at the longitudinal axis, L, or at the opposite top edge 370. The cutter 310 is said to have a greater or longitudinally extended volume of cutting material 310 adjacent a predesignated exposed or surface portion (*e.g.*, surface portion 350) that extends inwardly from the cutting or front face 320. In FIGS. 3B and 3C, this "longitudinally extended volume of cutting material" is denoted by reference 350'.

[0025] FIG. 3D illustrates engagement of the cutter 310 with the rock formation 312, thereby providing a depth of cut 316 into the formation 312. The engagement is provided as a result of an axial load N and a tangential load L applied through the cutter 310. The cutter 310 has the diamond table 322 extended opposite the cutter face 320 in the area of the wear flat 328, (*i.e.*, corresponding to 350 of

FIGS. 3B, 3C). At wear flat 328, the cutter 310 is subjected to both abrasive wear through contact under load to the rock 312 as well as heat generated to the cutter 310 from the energy exerted in the cutting process. By longitudinally extending the diamond table 322, more diamond volume is available to be worn during the drilling process, thereby confining or containing the wear flat or wear scar to the cutter material portion of the cutter 310. Such a longitudinally extended volume of diamond 350 life and subsequently better bit performance.

[0026] A variety of options, shown as FIGS. 3E-EH, accomplish extension of the diamond table 322 in the vicinity of the expected wear flat 328 to increase the amount of diamond available to be abraded as the cutter wears. Full face and partial diamond face geometries may be utilized for the cutter. In each of these vertical cross sections, of FIGS. 3E-3G, the longitudinally extended volume of cutting material is provided in the lower half of the cutter 310 and in adjacent a surface portion 350 expected or designated to correspond with the expected wear flat 328. In FIGS. 3H, the longitudinally extended diamond volume 350' is provided above, as well as below the longitudinally axis, ZZ.

[0027] FIG. 4 illustrates alternative embodiments of a cutter 410 according to the invention. FIGS. 4A, 4B, and 4C provide front, vertical cross sectional, and bottom views, respectively, of a second embodiment of the present invention. FIGS. 4G-4I provide yet further variations of this alternative embodiment. In these Figures, like elements are indicated using like reference numerals. Furthermore, in each further variation, the cutter 410 employs a diamond table 422 and a reinforcing structure 460 positioned adjacent the table 422.

[0028] Referring to FIGS. 4A-4C, the cutter 410 of this embodiment utilizes a reinforcing structure 460 integral to the diamond table 422. The reinforcing structure

460 also provides a longitudinally extended diamond table to increase the volume of diamond available for wear (*i.e.*, longitudinally extend diamond volume 450'). This feature will allow key areas of the diamond to be in a higher compressive stress state which is favorable to the reduction of fracture in the cutter. As shown in these additional Figures, there are a variety of geometrical shapes that may be utilized to form this embodiment of the cutter. Moreover, the reinforcing structure may be provided by a variety of cutting material, including polycrystalline diamond.

[0029] Referring to FIGS. 5A-5C, another embodiment of the cutter of the present invention is illustrated. The cutter 510 differs in that a geometrical shape of diamond 522 is confined within the frontal area of the cutter 510 and supported partially therearound by the adjacent substrate 524. If the diamond material is located at an angle to the centerline of the cutter 510, the extend of diamond material in contact with the formation during operation is extended, again creating more diamond material volume available for wear.

[0030] By configuring the geometric shape over most of the surface area with the substrate 524, the diamond is stressed favorably to better resist fracture. The stresses to which the diamond is subjected are created as part of the fabrication process. The entire cutter 510, including diamond and substrate, are elevated to extreme temperature and pressure (sintering) to allow diamond to diamond grain growth. On cooling and reduction of pressure, the substrate has a tendency to shrink at a faster rate than the diamond because the coefficient of thermal expansion is higher in the substrate than in the diamond. The end result is that the diamond table 522 is compressionally stressed, whereas the substrate 524 near the diamond table 524 holds more tension. In this concept, the additional stresses created through the cutting

process are mostly directed to the diamond portion 522 of the cutter 510 already, which is in a more favorable stress state than the cutter substrate 524.

[0031] Referring now to FIG. 6, another embodiment of the present invention is illustrated. This cutter is related to the cutter of FIG. 5 in that not only is the majority of the diamond surface area in contact with the substrate but the diamond is completely surrounded by the substrate for a significant portion of the diamond volume. By surrounding the geometrical shape contained in the substrate, the favorable stresses in the diamond are further enhanced, as well has having some substrate support to the rear of the cutting portion of the diamond, which in most cases is an enhancement to the stress state of the diamond near the wear flat and substrate boundary of the cutter.

[0032] It should be noted that the above lateral cross-sectional views, in many embodiments, is substantially similar along the longitudinal length of the cutter portion. In each such view, the area of cutting portion in one half of the cross-section is larger than in the opposite half.

[0033] Referring to FIG. 7, an alternate embodiment of the cutter of the present invention is shown. The cutter 710 of this embodiment is similar to that of FIG. 6 in that the cutter 710 has a geometric shape which allows a different improved stress state for the diamond in addition to providing a more rigid structure relative to the highest applied loads. As shown in the lateral cross-sectional view of FIG. 7A, the cutting portion 722 occupies only a portion of the cutter 710. In this particular embodiment, the cutting portion 722 is substantially bounded by the substrate 724. It should be noted that any such cross-sectional view along the longitudinal length of the cutting portion 722 reveals the substrate 724 occupying a portion of the cross-sectional are and specifically, the circumference 718. In respect to the embodiment of

FIG. 7C, the area occupied by the cutting portion 722 is reduced as the longitudinal position approaches the back surface 760.

[0034] Referring to FIG. 8, yet another alternate cutter is illustrated. This cutter 810 is different from the previously described embodiments in that the substrate 824 is oriented with a rake angle opposite of the previous embodiments. The cutter 810 is also different because the diamond cutting portion 822 incorporated into the substrate 824 rather than a face of the substrate 824. This concept provides a cutter having either planar or non-planar diamond elements by altering the geometry of the diamond portion of the cutter assembly.

[0035] FIGS. 9 and 10 illustrate the wearing process applied to some of the embodiments of the cutters 910, 1010 of the present invention. The cutters 910, 1010 illustrated have a wear flat 928, 1028 that has been worn down by cutting into a rock formation. The wear flat 928, 1028, although worn, maintains its integrity because the wear flat 928, 1028 maintains mostly a diamond surface for the life of the cutter 910, 1010. Because the geometry and/or placement of the diamond has been modified, the substrate 924, 1024 does not become part of or integral to the wear flat 928, 1028 when the cutter 910, 1010 is eroded from cutting the rock formation.

[0036] It is thus believed that the operation and construction of the present invention will be apparent from the foregoing description. While the drill bit and drilling system shown and described have been characterized as being preferred it will be obvious that various changes and modifications may be made therein without departing from the spirit and scope of the invention.

WHAT IS CLAIMED IS:

1. A cutter element for use on a rotary drill bit attach to a drill string to cut earthen formations and the like, said cutter element comprising:

a cutting portion formed from cutting material adapted to cut the earthen formation; and

a substrate positioned adjacent the cutting portion;

wherein the cutting portion and the substrate form a body having a substantially planar front face, a longitudinal axis extending centrally through the front face and the substrate, and a circumferential surface extending inwardly from the front face and spaced outwardly from the longitudinal axis; and

wherein the cutting portion includes a cutting face providing at least a portion of the front face, the cutting portion extending longitudinally inward from the front face to a back surface engaging the substrate, such that a distinct, longitudinally extending volume of cutting material is provided and includes a predesignated portion of the circumferential surface that extends from the cutting face to the back surface, the predesignated circumferential surface portion being predesignated for wearing contact with the earthen formation.

2. The cutter element of Claim 1, wherein the back surface deviates from normal angular relation with the longitudinal axis, such that the longitudinal distance between the front face and locations on the back surface varies.

3. The cutter element of Claim 2, wherein the front face consists entirely of the cutting face of the cutting portion.

4. The cutter element of Claim 2, wherein the cutting portion is configured such that at least one longitudinal cross-section of the cutter element, generally normal to the front face, reveals a cross-sectional area of the cutting portion with a larger area on one side of the longitudinal axis than on an opposite side of the longitudinal axis.

5. The cutter element of Claim 2, wherein the cutting portion is configured such that at least one longitudinal cross-sectional view of the cutter element, generally normal to the front face, reveals an exposed circumferential surface of the cutting portion in one half of the cross-section that is longer than a corresponding exposed circumferential surface portion of the cutting portion on an opposite half of the cross-section.

6. The cutter element of Claim 2, wherein the cutting portion is configured such that a lateral cross-sectional view of the cutting element, generally normal to the longitudinal axis, reveals a larger area of the cutting portion concentrated in one half of the cross-section adjacent the predesignated circumferential surface portion than in an opposite half of the cross-section.

7. The cutter element of Claim 2, wherein at least one longitudinal cross-sectional view of the cutting element, generally normal to the front face, reveals a longitudinally extending area of the distinct longitudinal volume of cutting material, the area having a thickness that is reduced as the area extends in the longitudinally inward direction.

8. The cutter element of Claim 1, wherein the volume of cutting material located in the vicinity of the predesignated circumferential surface portion substantially larger than the volume of cutting material located in the vicinity of other portions of the circumferential surface.

9. The cutter element of Claim 1, wherein the substrate form a portion of the front face.

10. The cutter element of Claim 1, wherein a lateral cross-sectional view through the cutting portion, generally normal to the longitudinal axis, reveals the substrate forming a portion of the exposed circumference of the cutter element.

11. The cutter element of Claim 10, wherein the cutting portion is configured such that any lateral cross-sectional view through the cutting portion, generally normal to the longitudinal axis, reveals the substrate forming a portion of the exposed circumference of the cutting element.

12. The cutter element of Claim 1, further comprising a bore extending from a portion of the circumferential surface to a portion of the cutting face, the cutting portion being situated therein.

13. The cutter element of Claim 1, wherein the cutter portion includes a reinforcing cutter material providing the distinct longitudinally extending volume.

14. The cutter element of Claim 1, wherein the cutting material is polycrystalline diamond.

15. The cutter element of Claim 1, wherein the cutting portion and the substrate form a substantially rod shaped body having a circumferential surface spaced radially from and in generally parallel relation with the longitudinal axis.

16. A cutter element for use on a rotary drill bit of a drill string to cut earthen formations and the like, said cutter element comprising:

a cutting portion formed substantially from polycrystalline diamond material adapted to cut the earthen formation; and

a substrate positioned adjacent the cutting portion;

wherein the cutting portion and the substrate form a substantially rod shaped body having a substantially planar front face, a longitudinal axis extending centrally through the front face and the substrate, and a circumferential surface extending inwardly from the front face and spaced radially from the longitudinal axis; and

wherein the cutting portion includes a cutting face providing at least a portion of the front face, the cutting portion extending longitudinally inward from the front face to a back surface interfacing the substrate, such that a distinct, longitudinally extending volume of cutting material is provided and includes a portion of the circumferential surface that extends from the cutting face to the back surface, the circumferential surface portion being predesignated for wearing contact with the earthen formation; and

wherein the cutting portion is configured such that a lateral cross-sectional view of the cutting element, generally normal to the longitudinal axis, reveals a larger area of the cutting portion concentrated in one half of the cross-section adjacent the predesignated circumferential surface portion than in an opposite half of the cross-section.

17. The cutter element of Claim 16, wherein the cutting portion is configured such that at least one longitudinal cross-section of the cutter element, generally normal to the front face, reveals a cross-sectional area of the cutting portion with a larger area on one side of the longitudinal axis than on an opposite side of the longitudinal axis.

18. The cutter element of Claim 17, wherein the back surface deviates from normal angular relation with the longitudinal axis, such that the longitudinal distance between the front face and locations on the back surface varies.

19. The cutter element of Claim 18, wherein the cutting portion is configured such that at least one longitudinal cross-sectional view of the cutter element, generally normal to the front face, reveals an exposed circumferential surface of the cutting portion on one side of the longitudinal axis that is longer than a corresponding exposed circumferential surface portion of the cutting portion on an opposite side of the longitudinal axis.

20. The cutter element of Claim 16, wherein the front face consists entirely of the cutting face of the cutting portion.

21. The cutter element of Claim 16, wherein at least one longitudinal cross-sectional view of the cutting element, generally normal to the front face, reveals a longitudinally extending area of the distinct longitudinal volume of cutting material, the area having a thickness that is reduced as the area extends in the longitudinally inward direction.

22. The cutter element of Claim 16, wherein the volume of cutting material located in the vicinity of the predesignated circumferential surface portion is substantially larger than the volume of cutting material located in the vicinity of other portions of the circumferential surface.

23. The cutter element of Claim 16, wherein the substrate provides a portion of the front face.

24. The cutter element of Claim 16, wherein the cutting portion is configured such that any lateral cross-sectional view through the cutting portion, generally normal to the longitudinal axis, reveals the substrate forming a portion of the exposed circumference of the cutter element.

25. A method of drilling a borehole, comprising the steps of:

providing a drill bit having a plurality of cutting elements thereon, the cutting elements having,

a cutting portion formed substantially from polycrystalline diamond material adapted to cut the earthen formation; and

a substrate positioned adjacent the cutting portion;

wherein the cutting portion and the substrate form a substantially rod shaped body having a substantially planar front face, a longitudinal axis extending centrally through the front face and the substrate, and a circumferential surface extending inwardly from the front face and spaced radially from the longitudinal axis;

wherein the cutting portion includes a cutting face providing at least a portion of the front face, the cutting portion extending longitudinally inward from the front face to a back surface interfacing the substrate, such that a distinct, longitudinally extending volume of cutting material is provided and includes a portion of the circumferential surface that extends from the cutting face to the back surface, the circumferential surface portion being predesignated for wearing contact with the earthen formation; and

wherein the cutting portion is configured such that a lateral cross-sectional view of the cutting element, generally normal to the longitudinal axis, reveals a larger area of the cutting portion concentrated in one half of the cross-section adjacent the predesignated circumferential surface portion than in an opposite half of the cross-section;

mounting the bit on the end of a drill string;

directing the drill bit at a position such that the cutting elements engage the earthen formation at an angle, whereby the predesignated circumferential surface portion is in contact with the earthen formation; and

operating the drill string such that the drill bit and the cutting elements cut into the earthen formation, thereby creating a wear flat along the predesignated circumferential surface portion.

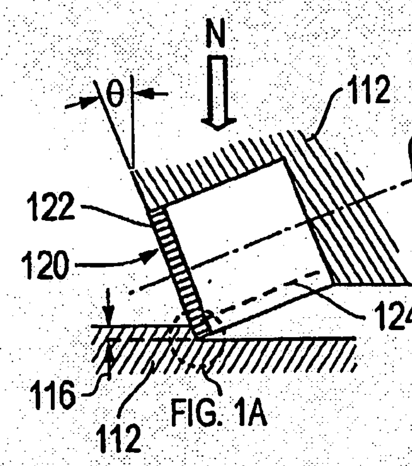

FIG. 1

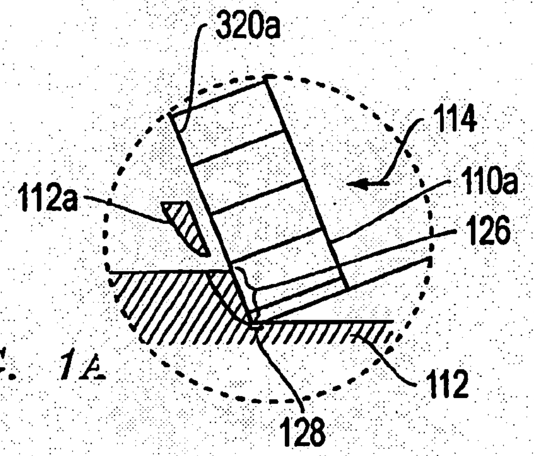

FIG. 1A

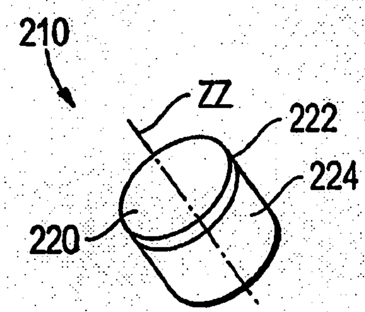

FIG. 2A

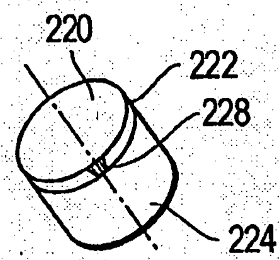

FIG. 2B

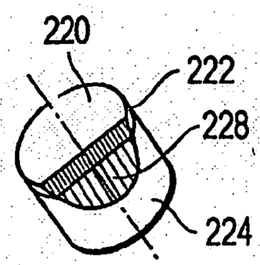

FIG. 2C

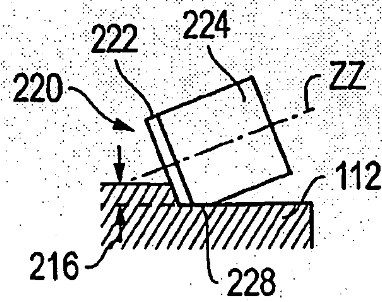

FIG. 2D

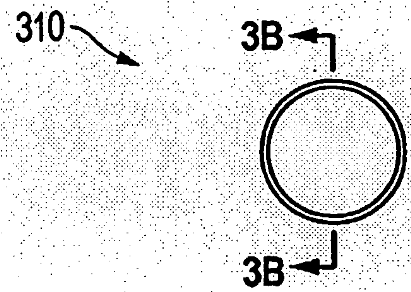

FIG. 3A

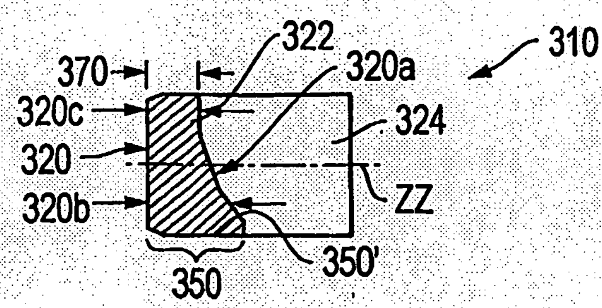

FIG. 3B

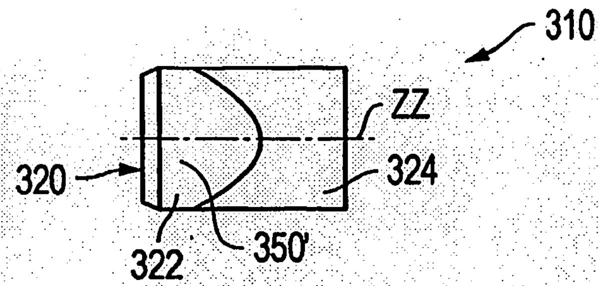

FIG. 3C

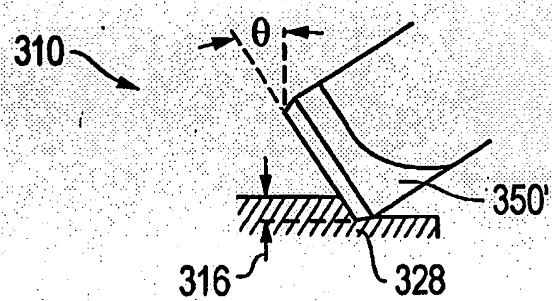

FIG. 3D

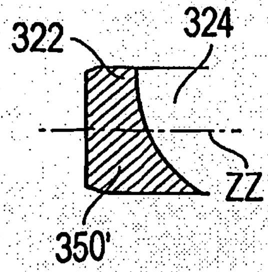

FIG. 3E

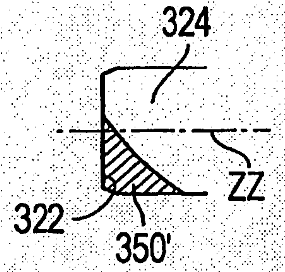

FIG. 3F

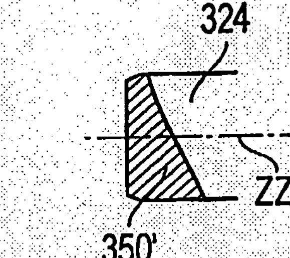

FIG. 3G

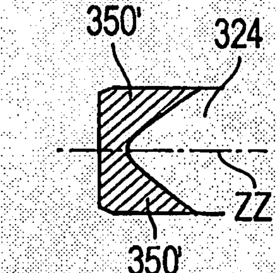

FIG. 3H

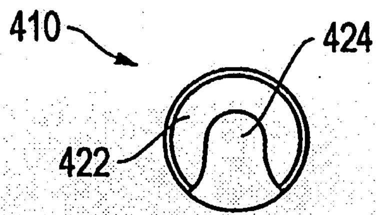

FIG. 4A

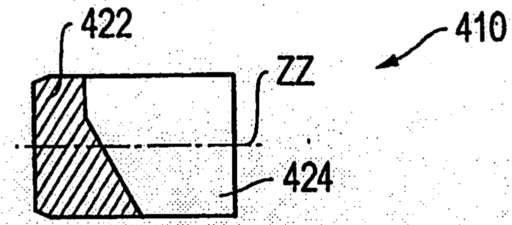

FIG. 4B

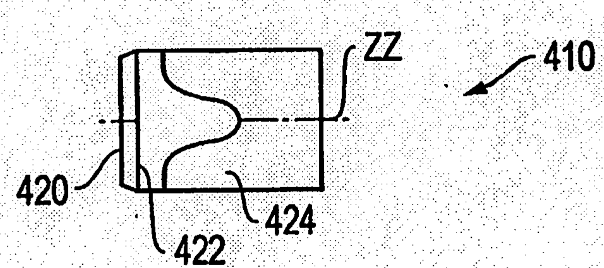

FIG. 4C

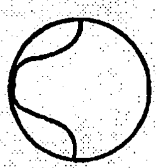

FIG. 4D

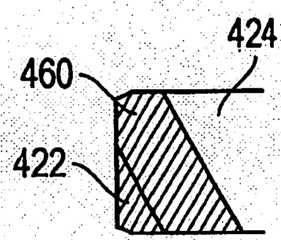

FIG. 4E

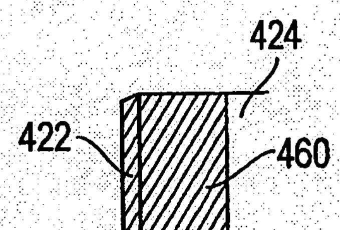

FIG. 4G

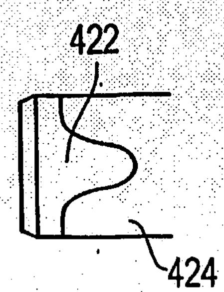

FIG. 4F

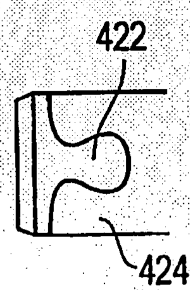

FIG. 4H

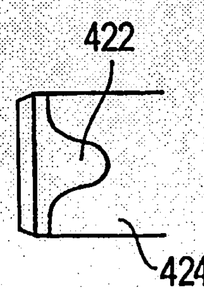

FIG. 4I

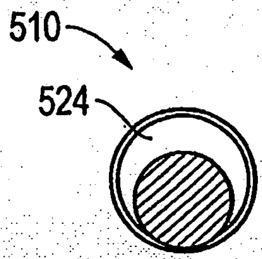

FIG. 5A

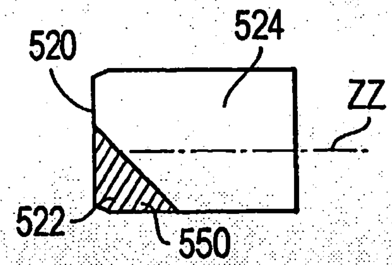

FIG. 5B

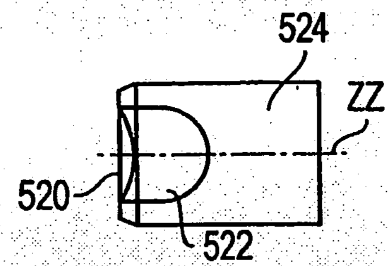

FIG. 5C

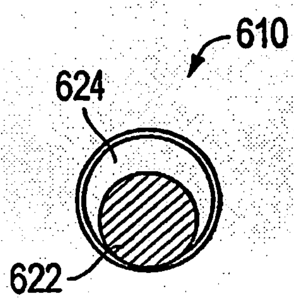

FIG. 6A

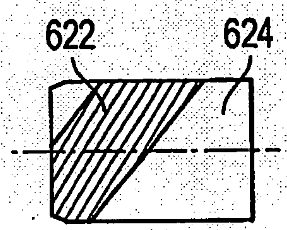

FIG. 6B

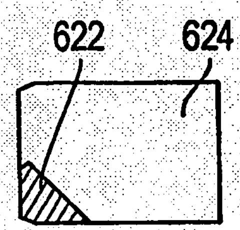

FIG. 6D

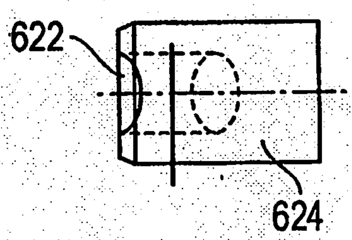

FIG. 6C

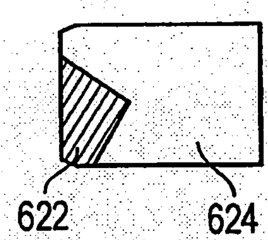

FIG. 6E

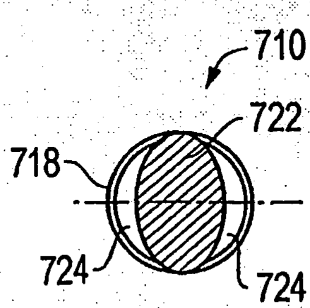

FIG. 7A

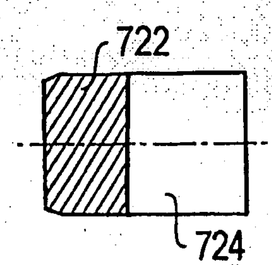

FIG. 7B

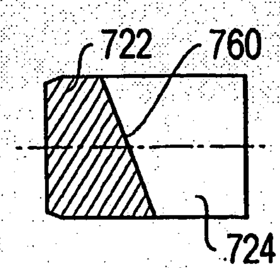

FIG. 7C

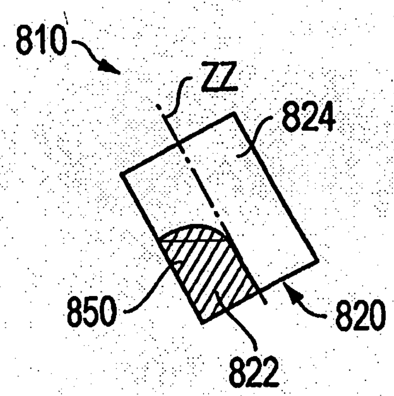

FIG. 8A

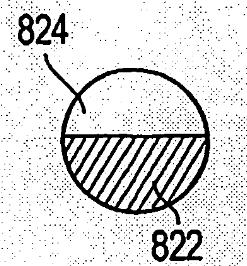

FIG. 8B

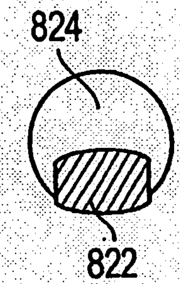

FIG. 8C

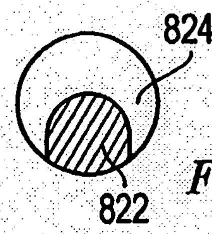

FIG. 8D

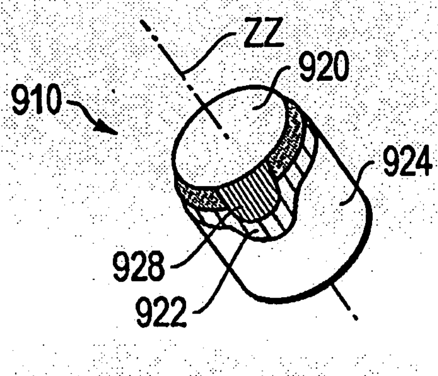

FIG. 9A

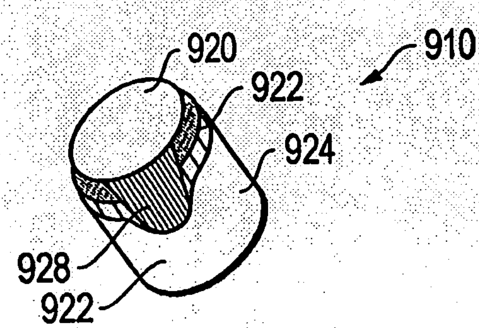

FIG. 9B

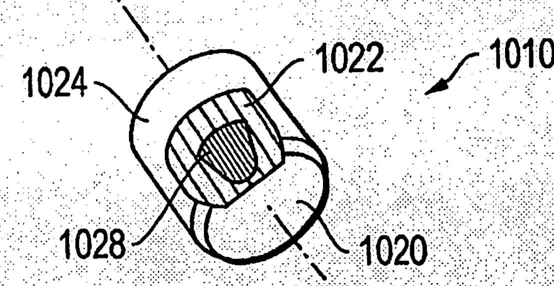

FIG. 10